Evaluation of the Relationship Among Time of Ocean Entry, Physical and Biological Characteristics of the Estuary and Plume Environment, and Adult Return Rates, 2004

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EXECUTIVE SUMMARY

This study examines the relationship between smolt-to-adult return rates (SARs) for spring Chinook salmon *Oncorhynchus tshawytscha* and the time of ocean entry in relation to physical and biological characteristics of the estuary and nearshore ocean plume environment. Study fish, originally from Willamette Hatchery, were transferred and reared by the Clatsop Economic Development Committee Fisheries Project and released in the lower Columbia River.

In 2004, the project's third year of releases, six groups of coded-wire tagged yearling spring Chinook salmon were transferred from Willamette Hatchery to net pens in Blind Slough in the Columbia River estuary, reared for 14 days and released at 10-day intervals (the last group reared for only 8 days) from 7 April through 20 May. Size and smolt development (gill Na^+-K^- ATPase activity) at release were similar among groups. Fungus and mortality increased in the net pens for the last two release groups due to warm water in Blind Slough during 2004.

Coded-wire tags from 2004 releases will be recovered from adults returning in 2006 and 2007, primarily to the Blind Slough terminal gill net fishery. The 2002 project releases provided an estimated 1,309 adults to the 2004 Blind Slough gill net fishery, with an additional 244 adults to the Youngs Bay gill-net, mainstem gill-net, and sport fisheries (1,559 total). SARs for the 4-year-old returns ranged from 0.34 to 1.55%, with additional returns of 5-year-old fish expected in 2005.

SARs for the serially released groups of spring Chinook salmon (when complete) will be integrated with information collected from ongoing studies funded by the Bonneville Power Administration (BPA) and others, characterizing the physical and biological conditions of the Columbia River estuary and plume. By enhancing our understanding of the linkages between ocean entry, the physical and biological estuarine and ocean conditions that the smolts encounter, and SARs, we might improve SARs for some salmon stocks by manipulating transportation tactics or hatchery release dates.

CONTENTS

INTRODUCTION

The effects of short- and long-term fluctuations in oceanographic and climatic conditions on survival of Pacific Northwest salmon *Oncorhynchus* spp. have received increased attention as salmon runs have declined (NRC 1996; Emmett and Schiewe 1997; Logerwell et al. 2003; Williams et al. 2000). Growth and survival of salmonids in their first days and months at sea appear critical in determining overall salmonid year-class strength. This is based on the relationship between returns of jack salmon, which spend only a few months at sea; numbers of adults returning from the same brood class in later years; and ocean purse-seine catches of salmonids in June, which correlate well with jack and adult returns (Percy 1992).

The Columbia River estuary has been significantly altered by human development (Sherwood et al. 1990; Weitkamp 1994), with seasonal flow patterns altered by dam construction and salmonid habitat changed as a result of dredging, diking, and urbanization. Exotic species introductions and large-scale salmonid hatchery programs have radically changed the species mix in the Columbia River estuary. Furthermore, ocean conditions appear to vary significantly both spatially and temporally at a variety of scales (Francis et al. 1998; Welch et al. 2000). The relative importance of these factors to juvenile salmon survival is not well understood.

Increasing our understanding of variations in estuarine and nearshore ocean environments, and the role these variations play in salmonid survival, could provide management options to increase adult returns. Smolt-to-adult-return (SAR) rates for PIT-tagged smolts that are collected and transported vary greatly within years (Williams et al. 2005). Past studies have documented little mortality during actual transport, and recent studies using juvenile radio tags have indicated rapid migration and high survival to the Columbia River estuary after release (Schreck and Stahl 1998). Recent studies of smolt survival during downstream migration through Snake and Columbia River reservoirs and dams have also shown little variation in survival within or between years (Muir et al. 2001; Williams et al. 2001). Therefore, changes in direct survival during migration through fresh water do not appear to explain observed changes in SARs for groups of fish within or between years.

Characterization of the conditions that smolts encounter in the estuary and nearshore ocean and of SARs on a temporal basis should allow us to identify which estuarine or ocean biological/physical conditions are correlated with high or low levels of salmon ocean survival. Managers can potentially use this information to determine optimal times for hatchery releases, or whether to transport smolts from collector dams or allow them to migrate naturally to synchronize their arrival to the estuary and nearshore

ocean during optimal conditions. Furthermore, information from this study may help to determine if the delayed mortality or "D" observed for transported fish is in part due to a difference in ocean entry timing between transported and inriver fish.

Conditions that vary in the estuary and nearshore ocean that may affect salmonid survival include changes in turbidity, the abundance of predators (birds, fish, and marine mammals), alternative prey for those predators (northern anchovy *Engraulis mordax*, Pacific herring *Clupea pallasi*, Pacific sardine *Sardinops sagax*, and euphausiids), and the salmonids' own prey (optimally allowing smolts to grow rapidly, reducing their vulnerability to predators). Dramatic changes in predator and baitfish populations off the coast of Oregon and Washington have been observed in recent years (Emmett and Brodeur 2000; Emmett et al. 2001).

This study examines the relationships among time of salmonid ocean entry, physical and biological characteristics of the Columbia River estuary and nearshore plume environment, and SARs for yearling Chinook salmon *O. tshawytscha*. The objectives are to:

1) estimate SARs of serially released yearling Chinook salmon through the spring migration period,

2) characterize variations in the physical and biological conditions in the Columbia River estuary and nearshore ocean environment during release periods,

3) determine the level of physiological development and disease status of smolts at release,

4) correlate SARs with environmental conditions at release, and

5) identify potential indicators (biotic, abiotic, or a combination of both) of salmonid marine survival that could be used by management to improve SARs.

In addition, the results from this study will provide valuable information to the Clatsop Economic Development Committee Fisheries Project (CEDC) to assess potential release strategies to maximize SARs.

METHODS

In the fall of 2003, about 170,000 spring Chinook salmon (Willamette stock) were obtained from Oregon Department of Fish and Wildlife (ODFW), divided into six groups of about 28,000 fish each, and reared at Willamette Hatchery in separate raceways (two groups per divided raceway). Each of the six groups were coded-wire tagged (CWT) with a different tag code (Table 1). About 2,000 fish in each group were also tagged with passive integrated transponder (PIT) tags (Prentice et al. 1990; Table 2). PIT tags were used for estimates of avian predation by Caspian terns *Sterna caspia* and double-crested cormorants *Phalacrocorax auritas* nesting on East Sand Island at River Kilometer (rkm) 8 in the Columbia River estuary (Ryan et al. 2001). After tagging, raceways were periodically swept with a magnet to collect shed PIT tags, and all mortalities were scanned for PIT tags to determine final PIT tag release numbers. Feeding rates were adjusted so that each group attained a similar size at release (target size of 140-150 mm.)

Every 10 days from late March through the middle of May 2004, individual groups of yearling Chinook salmon were transported by truck (5,000 gal) to net pens located in Blind Slough in the lower Columbia River (Fig. 1). The net pens, owned and operated by the CEDC, were 6.1-m wide by 6.1-m long by 2.4-m deep. Using the CEDC facilities reduced the number of hatchery fish needed to evaluate adult returns. The facility has high return rates and the lower Columbia River terminal fishery is heavily monitored to recover CWTs. Furthermore, the mortality associated with migration through fresh water is minimized because the CEDC facilities are located in the Columbia River estuary.

Smolts were sampled prior to release to determine their level of physiological development and health. Gill Na^+-K^- ATPase activity was measured on the date of arrival in Blind Slough and 14 days later at release. Gill filaments were trimmed from the gill arches of 15 fish on each sample date; placed into microcentrifuge tubes containing sucrose, ethylenediamine, and imidazole (SEI); and immediately frozen on dry ice. Gill Na^+-K^- activity was determined according to the method of McCormick (1993). Fish health was inspected monthly and just prior to transport to Blind Slough, and inspections included an ELISA for bacterial kidney disease (Pascho et al. 1991) from each raceway by an Oregon State University pathologist.

While in the net pens, fish were fed Oregon Moist Pellet[1] 5 days/week to satiation. Mortalities were removed from the net pens, counted, and scanned for PIT tags.

1 Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA

Table 1. Release dates, coded-wire tag codes, percent with CWT, and percent with adipose clip for Willamette Hatchery yearling spring Chinook salmon released into Blind Slough in 2004.

Release date	Tag code	CWT (%)	Adipose clip (%)
7 April	093906	93.5	99.6
16 April	093903	96.3	99.5
26 April	093907	95.6	99.1
6 May	093904	97.2	99.7
17 May	093908	97.4	98.9
20 May	093905	97.0	99.5

Table 2. Yearling spring Chinook salmon release dates, number of PIT tags shed in raceways, PIT-tag mortalities, and total numbers with PIT tags released into Blind Slough in 2004.

Release date	Number PIT-tagged	Number of shed tags and mortalities	Number with PIT tags released
7 April	2,005	828	1,177
16 April	2,002	9	1,993
26 April	2,003	64	1,939
6 May	2,003	14	1,989
17 May	2,003	134	1,969
20 May	2,003	169	1,834

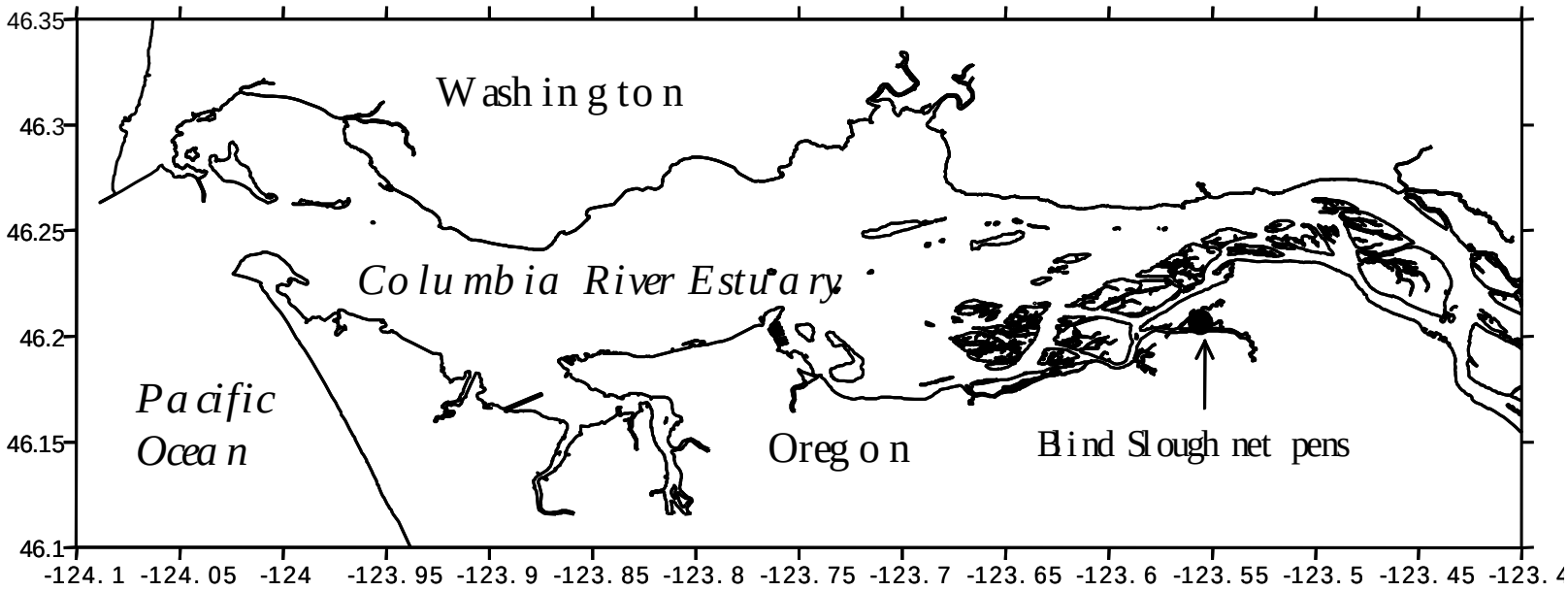

Figure 1. Study area showing location of Blind Slough net pens in the upper Columbia River estuary where Willamette Hatchery yearling spring Chinook salmon were acclimated and released in 2004.

At the time of release, about 500 fish from each group were individually measured, and small groups were weighed and counted to determine size at release.

Environmental conditions within the estuary and nearshore ocean environment, both biotic and abiotic, are being characterized for each release time, primarily by utilizing data from existing Columbia River estuary and ocean studies. Physical conditions being characterized during ocean and estuary studies include water temperature, salinity, and current at various depths using anchored buoys in the Columbia River estuary and plume (Oregon Graduate Institute Study, unpublished data). The populations of salmonid predators (Pacific hake *Merluccius productus*, Pacific mackerel *Scomber japonicus*, and jack mackerel *Trachurus symmetricus*), along with the abundance of alternative prey for those predators and for salmonids (northern anchovy, Pacific herring, Pacific sardine), are being sampled by surface trawl in the Columbia River plume at about 10-day intervals. Our releases were timed to coincide with that sampling effort.

PIT-tag codes from our releases are being recovered in an ongoing study on Rice and East Sand Island to determine losses of PIT-tagged fish from avian predation (Ryan et al. 2001). Our releases will add important information to this study because they are made at regular intervals with fish of known physiological and disease status. Our release groups are the only PIT-tag releases in the Columbia River estuary made at regular intervals over the nesting season of piscivorus birds. This release schedule will provide data for estimates of smolt vulnerability to predation through time, and the estimates can be compared with those of salmonids migrating from above Bonneville Dam.

Complete adult returns from our serial releases will be evaluated and correlated with the biotic and abiotic conditions smolts encountered in the Columbia River estuary and nearshore ocean. The first adults from releases in 2002 returned to Blind Slough in 2004, and these returns will be complete in 2005. Adults from 2003 releases will return in 2005 and 2006, and adults from 2004 releases will return in 2006 and 2007. Adult returns in the lower Columbia River terminal gill-net fishery are monitored at about a 50% sample rate by ODFW. Adult return rates of PIT-tagged spring/summer Chinook salmon passing Bonneville Dam or transported and released below Bonneville Dam will also be compared to CEDC adult returns from releases with similar times of ocean entry. Because of the complexity of the marine environment, it is anticipated that multiple years of study will be required to confidently correlate salmonid smolt survival with specific estuary/near-shore ocean environmental conditions.

RESULTS AND DISCUSSION

In 2004, six groups of from 16,168 to 27,644 yearling spring Chinook salmon with CWTs (with about 2,000 per group also PIT-tagged) were released into Blind Slough at 10-day intervals between 7 April and 20 May (Tables 2-4). The numbers of fish released with CWTs and adipose clips ranged from 15,117 to 26, 712 (Table 4). Our goal of keeping fish length constant among release groups was largely achieved, with mean length per group ranging from 143 to 155 mm FL at release (Fig. 2; Table 4).

Mortality while fish were rearing at Willamette Hatchery was lower in 2004 than in 2002 and 2003. Prior to transfer to Blind Slough, low levels of BKD were identified in 2 of 15 fish sampled from the 17 May release group. Fungus was observed on some fish on arrival at Blind Slough from the last two groups (17 May and 20 May release groups). Mortality for these two groups increased just prior to transfer to Blind Slough. Mortality during the 14-day acclimation period in Blind slough net pens ranged from 0.37 to 12.6% per group (Table 4). Mortality was highest for these last two groups, with the fungal infection apparently aggravated by the warm water in Blind Slough in mid- to late May. The last release group (20 May) was liberated 7 days early because of increasing fungus and mortality. Adult return data from the release group of 20 May 2004 may have little value because many of the fish had fungus at release.

Gill Na^+-K^- ATPase activity followed a typical development pattern for yearling spring Chinook salmon, peaking in mid-May (Fig. 3). Acclimation in the Blind Slough net pens appeared to stimulate gill ATPase activity in all release groups (although it was not measured at release in the last group). Water temperatures in Blind Slough were higher than Willamette Hatchery and likely stimulated gill ATPase development. All groups had sufficiently high gill ATPase levels at release to enter seawater.

Water temperatures in the Columbia River (measured at Beaver Terminal, km 87) over the period of the releases increased steadily from 10.6 to 14.8°C. Turbidity and flows varied slightly among releases, with turbidity ranging from 4.7 to 5.5 nephelometric turbidity units (NTU) and flows ranging from 171 to 253 kcfs (Fig. 4). Additional information on physical and biological characteristics of the estuary and nearshore ocean plume environment have been entered into a database to correlate with future SARs.

Table 3. Transport dates from Willamette Hatchery, release dates and times into Blind Slough, and Blind Slough water temperature on arrival and at release during 2004.

Transport dates	Release dates	Release time	Water temperature on arrival (°C)	Water temperature at release (°C)
24 March	7 April	1600	8.9	11.1
5 April	16 April	1400	10.6	11.7
14 April	26 April	1300	12.2	12.8
22 April	6 May	1400	11.7	15.6
4 May	17 May	1300	15.6	15.6
13 May	20 May	1300	15.0	16.1

Table 4. Yearling spring Chinook salmon release dates, mean fork length (mm) and number/lb at release, percent mortality in net pens, total numbers released, and numbers with coded-wire tags (CWT) and adipose clips released into Blind Slough in 2004.

Release date	Fork length (s.e.)	Number/lb	Percent mortality	Number of fish released	Number with CWT and adipose clip released
7 April	143 (0.8)	14.3	0.43*	16,168	15,117
16 April	152 (0.7)	12.5	0.37	27,359	26,347
26 April	147 (0.8)	11.7	3.10	27,644	26,428
6 May	150 (0.7)	13.1	0.83	27,482	26,712
17 May	155 (0.7)	11.4	8.63	24,488	23,851
20 May	---	---	12.6	23,508	22,803

* 11,347 mortalities during transport from hatchery not included.

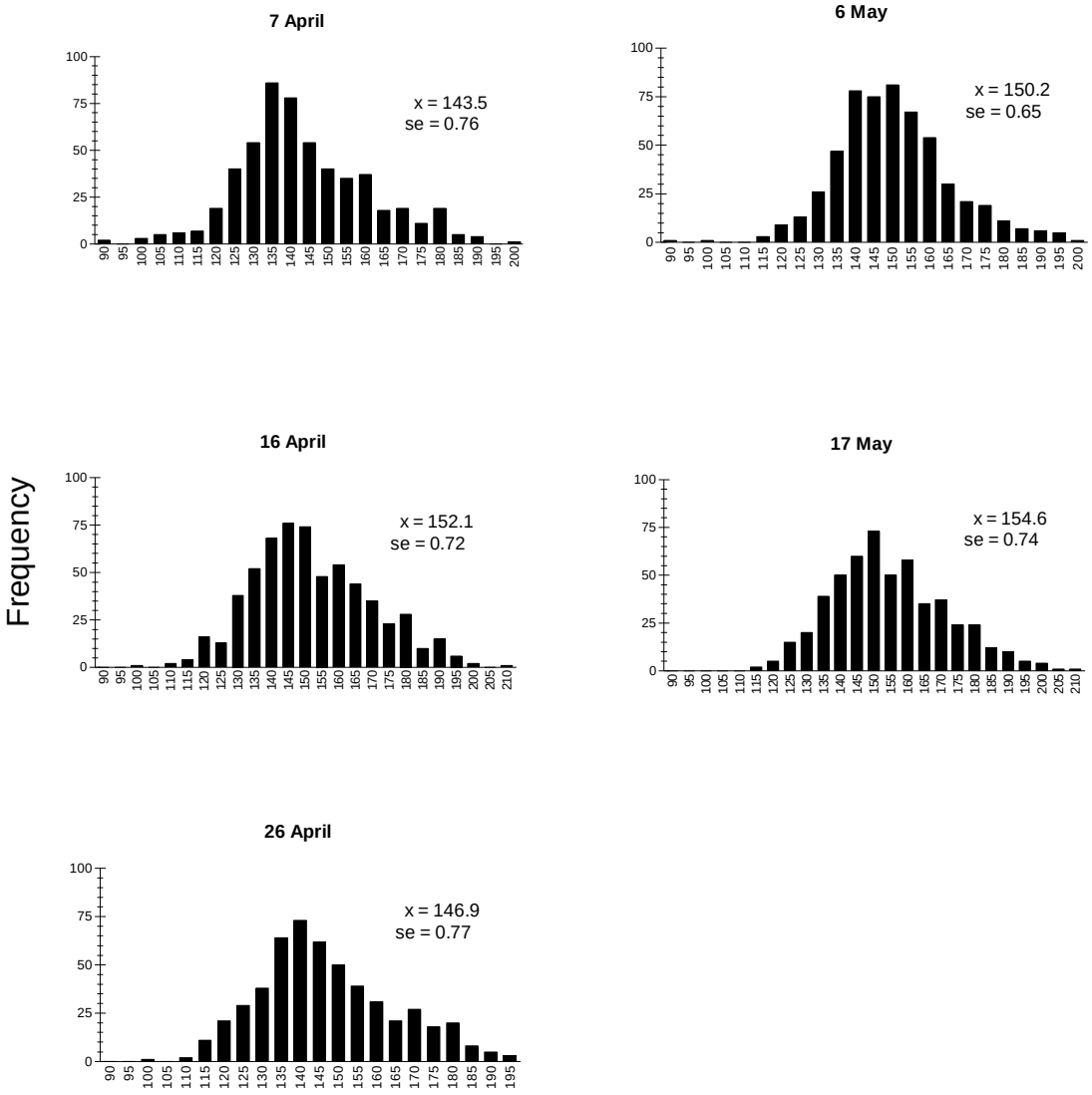

Figure 2. Length frequency (with mean and standard error) of Willamette Hatchery yearling spring Chinook salmon at release from net pens into Blind Slough during 2004. Length was not measured for the release on 20 May.

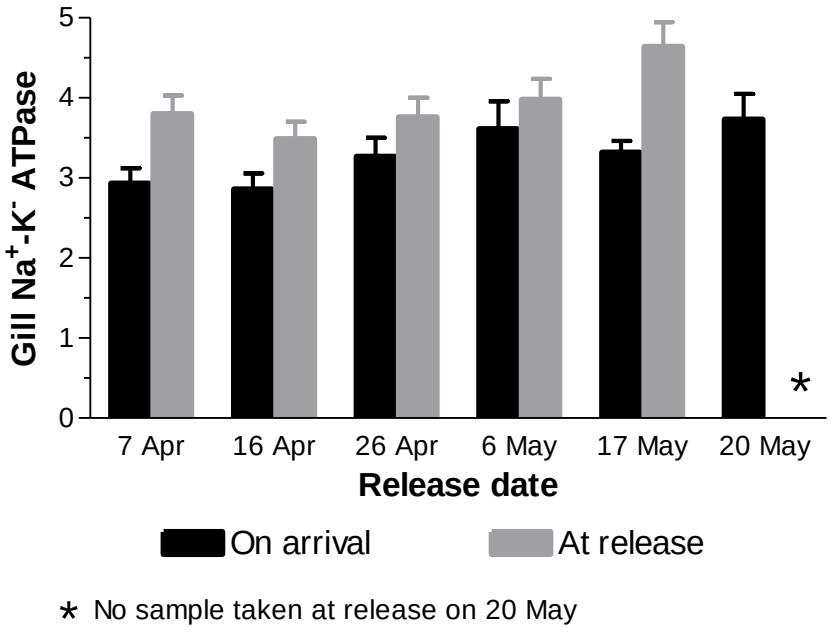

Figure 3. Mean gill $Na^{+}K^{-}$ ATPase activity *u*mol Pi · mg $Prot^{-1}$ · h^{-1} (with standard error) for Willamette Hatchery yearling spring Chinook salmon on arrival at net pens and at release 14 days later into Blind Slough, 2004.

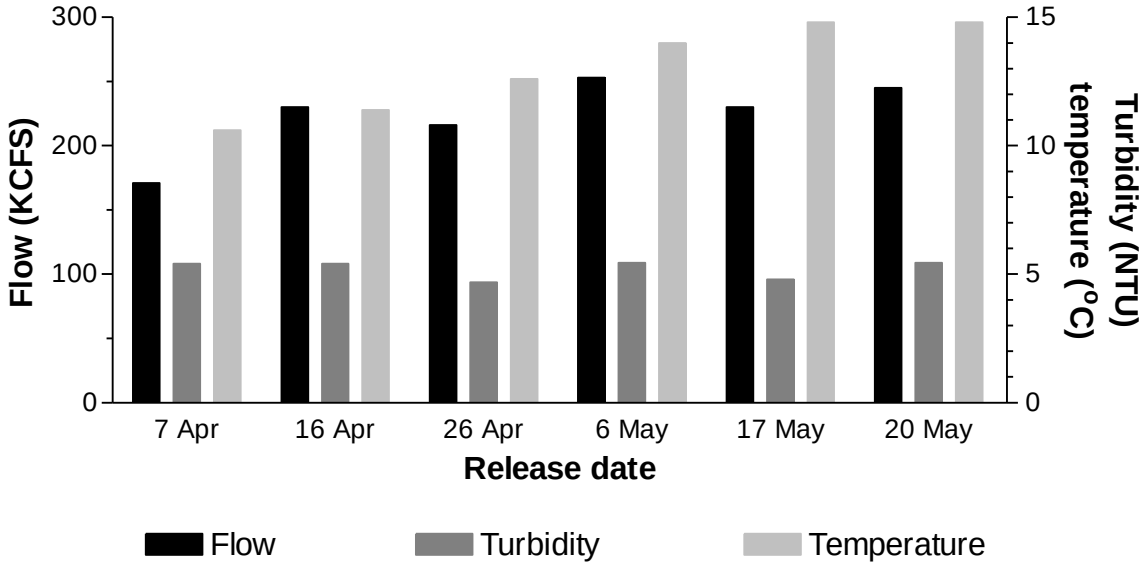

Figure 4. Flow (kcfs), turbidity (NTU), and water temperature (°C) measured at Beaver Terminal on each release date for Willamette Hatchery yearling spring Chinook salmon from net pens in Blind Slough during 2004.

The percentage of PIT tags (percent of each release group) detected on Columbia River estuary bird colonies for 2004 releases ranged from 2.5 to 5.7% with no apparent trend through time (Fig. 5). The percent detected on bird colonies in 2004 was lower compared to 2002 and 2003 releases for most groups. For 2002 and 2003 releases, there was a general trend of declining percent detected on bird colonies through time. During all three years, the percent detected at the bird colonies was higher for our releases than for upriver stocks (Brad Ryan, NOAA Fisheries, personal communication).

The first adults returned from 2002 releases to the 2004 Blind Slough terminal gill-net and other fisheries. An estimated (expanded for tag loss and sample rate) 1,309 4-year-old fish were captured in the Blind Slough gill-net fishery, 31 in the Youngs Bay gill-net fishery, 38 in the mainstem gill-net fishery, 115 in Gnat and Big Creek sport fishery, and 60 in the Lower Columbia River sport fishery, for a total of 1,553 (Table 5). SARs (4-year-old fish only) for the six release groups ranged from 0.34 to 1.55% (Fig. 6).

Eight PIT-tagged adults from 2002 releases were detected passing Bonneville Dam in 2004. Expanding this number for the non PIT-tagged population, an estimated 57 adults passed Bonneville Dam from our 2002 releases. Fish were acclimated in Blind Slough net pens for 10 days in 2002. The acclimation period was increased to 14 days in 2003 and 2004.

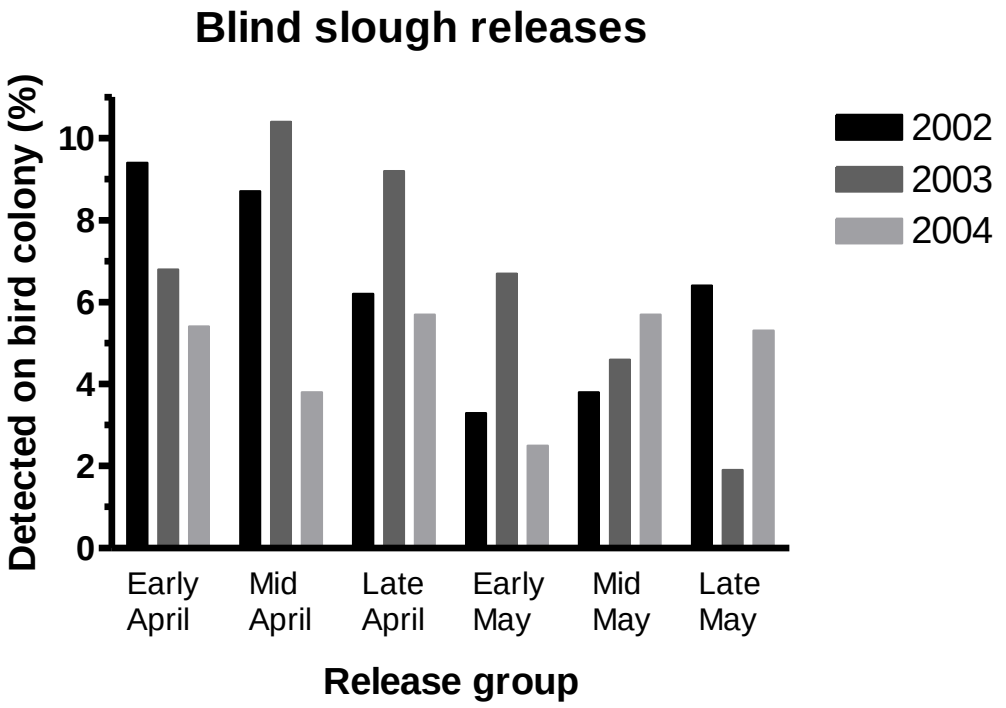

Figure 5. PIT tags (percent of each release group) detected on Columbia River estuary bird colonies from releases of spring Chinook salmon from Blind Slough net pens, 2002-2004.

Table 5. Number of 4-year-old adult spring Chinook salmon returning in 2004 to various fisheries from net-pen releases in Blind Slough in 2002. Expanded numbers (Exp.) represent actual coded-wire tag recoveries expanded for tag loss and sampling rate.

	2002 release date											
	10 April		19 April		30 April		10 May		20 May		30 May	
	Actual	Exp.	Actual	Exp.	Actual	Exp.	Actual	Exp.	Actual	Exp.	Actual	Exp.
Blind Slough gill net	57	198	73	301	52	224	68	235	70	275	19	76
Youngs Bay gill net	2	10	1	4	1	4	2	8	1	5	0	0
Mainstem gill net	2	5	2	5	3	8	0	0	8	20	0	0
Gnat and Big Cr sport	0	0	2	17	0	0	5	56	3	42	0	0
Main stem sport	1	6	1	6	1	7	2	12	2	23	1	6
Total all fisheries	62	219	79	333	57	243	77	311	84	365	20	82

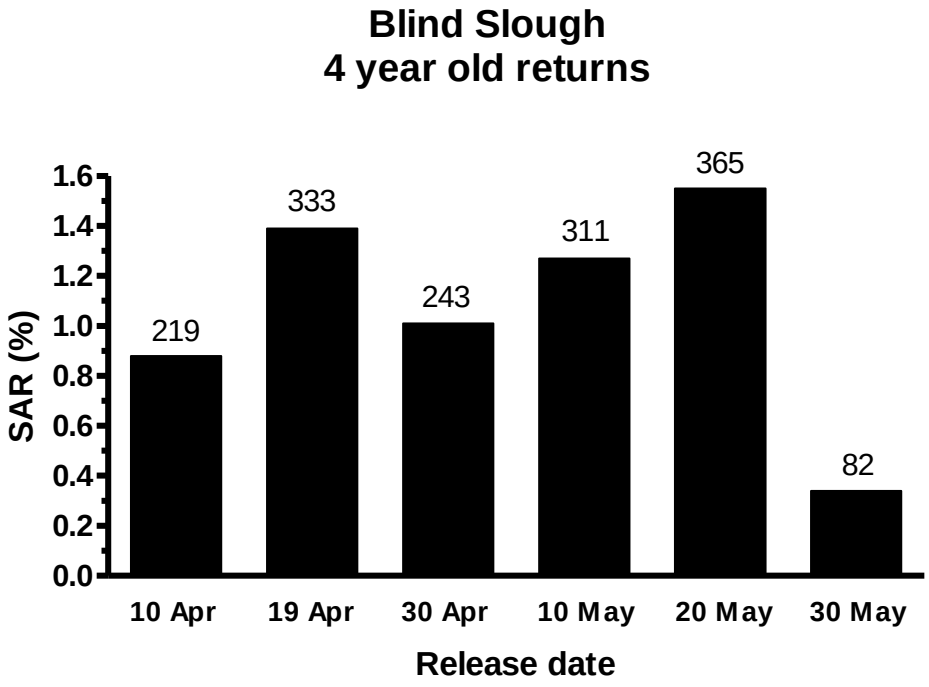

Figure 6. The percent smolt-to-adult return (SAR) of 4-year-old spring Chinook salmon released from Blind Slough net pens in 2002. Five-year-old fish will return in spring 2005. The estimated number of adults from all fisheries (gill net and sport) returning in 2004 is shown above each bar.

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